Investigation of skew piercing and upsetting effect on wheel steel mechanical properties

A V Fomin[1, 4], V P Romanenko[1], A N Nikulin[2] and A A Sevastjyanov[3]

[1] National University of Science and Technology MISiS, Moscow, 119991, Russia
[2] Federal State Unitary Enterprise, I.P.Bardin Central Research and Development Centre chermet, Moscow, 105005, Russia
[3] Vyksa Metallurgical Works, OJSC, Vyksa, 607060, Russia

E-mail: [4] fominmisis84@mail.ru

Abstract. The article states the results of the investigation of the skew piercing effect on the wheel steel mechanical properties. The comparative analysis is based on the comparison of mechanical properties of wheel steel samples manufactured by upsetting and heat treatment of the initial cast billets (option 1) and samples preliminarily pierced using the skew rolling mill with the extrusion ratio of $\mu \approx 1.49$ and feed angle of 12°, upset and heat treated (option 2). The values of elongation/contraction ratios of the samples made from solid workpieces are in the range 13.8–15/28–32%, and of hollow workpieces 14.2–15.8/26–32.9%. Strength properties of the wheel steel (for 1 and 2 variants) meet the requirements. The greatest differences in the properties of wheel steel of both variants were obtained during toughness tests. Toughness value of the wheel steel samples obtained by piercing, upsetting and subsequent heat treatment is ~2.5 times higher in both tangential and radial directions than the toughness of samples obtained only by upsetting and heat treatment. It is shown that piercing of workpieces in a screw rolling mill increases the toughness without reducing the strength properties, which may be due to intense shear deformations causing the processing of the cast macrostructure and the formation of a spiral-shaped grain structure.

1. Introduction

Railway wheels operation reliability and performance can be improved if plastic properties are enhanced provided that metal strength properties are maintained that can be achieved through preliminary deformation processing [1, 2]. Development of new processes and improvement of deformation processing parameters are among the effective methods of controlled influence on physical and mechanical properties of metal products [3–8]. In this regard the skew rolling is considered to be of high industrial capacity. Intense development of shear deformations even with relatively small reduction ratios can contribute to the processing of the metal structure both in the peripheral and central layers of the billet [9–11].

Preliminary processing of the initial cast billet structure by means of skew piercing of solid billets into shells [12–17] can increase the production effectiveness and enhance quality of railway wheels, hollow railway axles [18].

Investigation has been performed to evaluate effect of skew piercing and upsetting on wheel steel mechanical properties. The comparative analysis is based on comparison of mechanical properties of wheel steel samples manufactured by upsetting and heat treatment of initial cast billets (option 1) and samples preliminarily pierced, upset and heat treated (option 2).

2. Conditions for investigation

2.1. Samples material
Samples with metal cast structure with the diameter of 100 mm and length of 300 mm from steel type T (GOST 10791) cut from the peripheral and mid portion of the wheel workpiece are used as initial workpieces for the investigation [19]. The sketch of sampling from wheel workpieces is given in Figure 1.

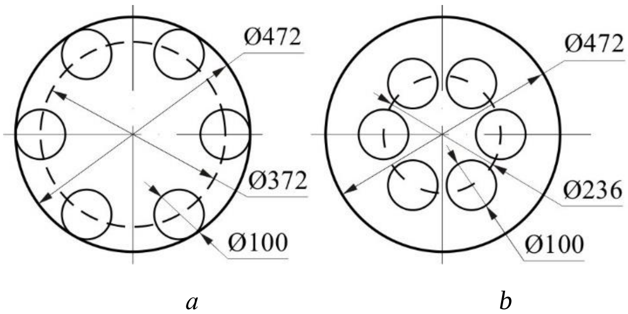


Figure 1. The sketch of sampling from wheel workpieces:
a – from the peripheral portion, *b* – from the mid portion.

2.2. Equipment
Piercing was performed using the two-roll skew rolling mill MISiS-130D. The two-roll piercing mill MISiS-130D with guide shoes is equipped with barrel-type work rolls with the diameter of 430 mm and length of 320 mm that are of bi-conical shape with the entrance and exit cones generatrix inclination angle of 3° and rolls highest points 10 mm wide located in the mid-section of the barrel. The rolls rotation rate is 57 rpm. Samples' upsetting was performed using the press power of 0.25 MPa.

2.3. Investigation methods
Piercing of samples into shells was performed at the metal heating temperature of 1200–1220 °C using the plug with the diameter of 29 mm provided that the following adjustment parameters are used for the mill:

- reduction in the rolls highest point is 15 %;
- feed angle is 12°;
- reduction factor is $\mu \approx 1.49$

The dimensions of solid samples for upsetting are as follows: the outside diameter is 100 mm, and the height is 65 mm. The sizes of hollow samples manufactured by piercing using the skew rolling mill are as follows: the outside diameter is 88 mm, the inside diameter is 32 mm and the height is 96 mm.

Upsetting of solid and hollow samples was performed at the billets heating temperature of 1200–1220 °C and the working tool travel rate of $v = 60$ mm/min. Billets upsetting using the press was performed in plane-parallel plates to the finite height of 23.5 mm.

Upon upsetting completion, both types of billets (initial cast billets and billets pierced using the skew rolling mill) were subject to heat treatment applicable for the manufacturing process intended to enhance end-user performance of finished products using the parameters that simulate interrupted quenching of railway wheel rims. Billets heat treatment parameters during quenching are as follows: heating up to 870 °C in the furnace and subsequent vacuum holding during 1 hour; transfer to the salt bath with the melt temperature of 570 °C and holding during 10 minutes, followed by cooling in air. Upon quenching, billets were subject to tempering at the heating temperature of 500–520 °C, with the holding time of 2 hours in the furnace under this temperature.

Thereafter, upset solid and hollow heat treated billets were used for taking samples to perform comparative assessment of wheel steel mechanical properties.

Investigation of billets metal mechanical properties was carried out using the samples with the test section diameter of d_{test} = 3 mm as per GOST 1497 [20]. Determination of metal mechanical properties was executed using the testing unit Instron with the deformation rate of ≈10^3sec^{-1}. The impact strength was determined using the samples of 5×10×55 mm size with U-notch 2 mm deep as per GOST 9454 [21]. Samples impact testing was carried out using the pendulum impact testing machine of PCB-30 model. The mechanical properties and impact strength of samples metal were determined at the temperature of +20 °C.

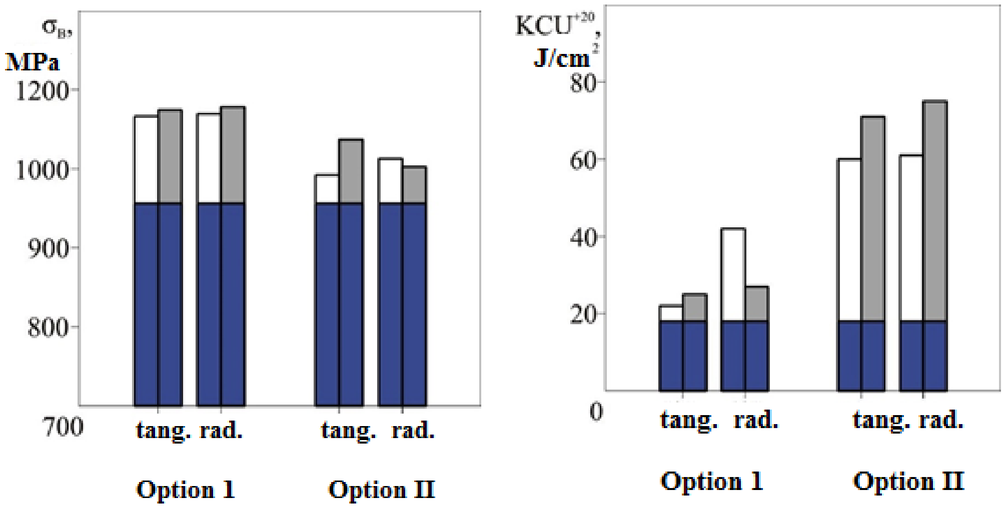
3. Results and discussion

As a result of the studies performed, it was established that the mechanical properties of solid and hollow billets metal upon upsetting using the press followed by heat treatment comply with the requirements of GOST 10791 for finished railway wheels, Figure 2. Values of the percentage elongation /contraction of samples manufactured from solid billets are within the range of 13.8–15/28–32 %, for hollow billets: 14.2–15.8/26–32.9 %.

As a result of deformation and heat treatment, the maximum variations in the wheel steel are identified for impact strength.

Wheel steel samples impact strength achieved by piercing, upsetting and subsequent heat treatment is by ≈2.5 times higher than the impact strength of samples that underwent upsetting and heat treatment only, both in the tangential and radial directions.

A higher level of wheel steel impact strength can be caused by intense shear deformations due to which processing of the cast macrostructure is carried out and swirl-pattern macrostructure is formed [22–25].



a б

- initial billets cut from the ingot mid-section;
- initial billets cut from the ingot peripheral portion;
- specification level complying with GOST 10791-2011.

Figure 2. Mechanical properties of wheel steel upon upsetting and heat treatment:
a – tensile strength (σ_B), б – impact strength (KCU^{+20}); option I – mechanical properties of wheel steel upon upsetting of solid billets and heat treatment, option II – mechanical properties of wheel steel upon upsetting of pierced billets and heat treatment.

For products that undergo high dynamic impact loads during operation, enhancement of impact strength can contribute to the increase of their operability and reliability. Therefore, it should be expected that application of billets preliminarily pierced using the skew rolling mill for manufacture of railway wheels will allow significantly increasing their quality and performance.

4. Conclusions

Based on the investigation performed it is proved that skew piercing allows for significant enhancement of impact strength with no deterioration of strength properties. It can be expected that application of billets preliminarily pierced using the skew rolling mill that have better performance parameters as compared to cast billets for production of railway wheels will contribute to the improvement of wheels performance and enhancement of technical and economical parameters of the production process.

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